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Global Emerging Sciences and Technology Assessment

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14. ABSTRACT

The goal of this project is to analyze all of the factors that provide guidance into choosing the best basic research investments for AFOSR outside the United States. Part 1 will focus on the Asia/Pacific Region, nominally the coverage area for the Asian Office of Aerospace Research and Development (AOARD). The study will take three different cuts into the Region: a broad look at what academic research institutions have grown to international prominence (through independent rating organizations) and trends related to that; a country specific detailed analysis for the nations most prominent in the region for S&T (Australia, India, Japan, Korea, Singapore, and Taiwan) along with some thoughts about smaller/emerging S&T nations (Indonesia, Malaysia, New Zealand, Thailand, and Vietnam) and the incredible growth in prominence of basic science in China (even though AFOSR cannot invest in that country); and, a discipline-specific analysis for the key science/technology areas of interest to AFOSR (Aeronautical/Space Sciences, Biotechnology, Brain/Cognitive Science, Chemistry/Materials Sciences, Computer Science, Mathematics, and Physics/Electronics).

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Global Emerging Sciences and Technology Assessment

Peter Friedland

Part 1: The Asia/Pacific Region

The goal of this project is to analyze all of the factors that provide guidance into choosing the best basic research investments for AFOSR outside the United States. Part 1 will focus on the Asia/Pacific Region, nominally the coverage area for the Asian Office of Aerospace Research and Development (AOARD). The study will take three different "cuts" into the Region: a broad look at what academic research institutions have grown to international prominence (through independent rating organizations) and trends related to that; a country specific detailed analysis for the nations most prominent in the region for S&T (Australia, India, Japan, Korea, Singapore, and Taiwan) along with some thoughts about smaller/emerging S&T nations (Indonesia, Malaysia, New Zealand, Thailand, and Vietnam) and the incredible growth in prominence of basic science in China (even though AFOSR cannot invest in that country); and, a discipline-specific analysis for the key science/technology areas of interest to AFOSR (Aeronautical/Space Sciences, Biotechnology, Brain/Cognitive Science, Chemistry/Materials Sciences, Computer Science, Mathematics, and Physics/Electronics).

The study will attempt to identify emerging science trends of relevance to the USAF, specific national and cross-national investments and programs where collaboration would make sense, and institutions, laboratories, and individual scientists/technologists worth considering for AFOSR investment. In addition, recommendations will be provided for further discovery in the form of field trips, discussions with national science agencies, and further literature study/conference attendance.

I. Analysis of Asia/Pacific Overall Science and Technology

While "fundable" research is not exclusively the province of academic institutions—there are certainly both government (e.g NICTA in Australia) and private (e.g. Riken Brain Science Institute in Japan) facilities worthy of consideration—colleges and universities will make up the strong majority of any AFOSR portfolio outside the U.S. The goal of AFOSR is to fund the best and brightest globally; work outside the U.S. is supported only if it is of quality equal to domestic research and complementary to and/or collaborative with research in the U.S. So examining the ranking of academic institutions is a useful starting point in this exercise. AFOSR supports individuals not institutions, but the best institutions do tend to attract among the best individuals. Perhaps at least as important for the AFOSR discovery process as absolute rankings

is the progression in rankings over time, since a strong upward trend would signify increasing quality of faculty perhaps spurred by government investment.

Today there are a host of organizations generating such rankings including overall academic rank, by broad areas (like physical sciences, social sciences, or engineering), and by specific discipline (like chemistry, computer science, or nanotechnology). Many different ranking mechanisms are employed. This section will describe the results of examining many of those studies, recommend the best ones, and explain how that analysis can be used as a tool for investment discovery.

Three organizations produce well-publicized rankings based upon multiple criteria: Times Higher Education (THE) an offshoot publishing company from the Times of London, Quacquarellli Symonds (QS) a private higher education consulting firm located in London, and the Academic Ranking of World Universities (ARWU) from the Shanghai Jiao Tong Univeristy. In addition, three more specialized ranking organizations are worth examining: the Nature Global Publishing Index from the Nature family of 18 highly prestigious journals, the University of Groningen ranking from the Netherlands, and the Webometrics rankings from the Cybermetrics Laboratory of the Consejo Superior de Investigaciones Científicas, the public research institution of Spain.

Times Higher Education

THE uses a weighted average of teaching quality (30%), research dollars received (30%), total citations in the literature (30%), international character of the faculty and students (7.5%) and industrial revenue received in patents and licenses (2.5%) to rank. These criteria tend to favor well-established, well-funded universities. 16 Asia/Pacific universities make the top 100: University of Tokyo (23), National University of Singapore (26), University of Melbourne (34), University of Hong Kong (43), Seoul National (Korea) (44), Peking University (45), Australian National University (48), Tsinghua University (China) (50), Kyoto University (52), KAIST (Korea) (56), Hong Kong University of Science and Technology (57), POSTECH (Korea) (60), University of Queensland (Australia) (63), University of Sydney (72), Nanyang Technology University (Singapore) (76), and Monash University (Australia) (91).

In the second 100, we find Chinese University of Hong Kong, Tokyo Institute of Technology, National Taiwan University, Osaka University, Tohoku University (Japan), Yonsei University (Korea), University of New South Wales (Australia), University of Auckland (New Zealand), and University of Western Australia—all of those in no particular order. Comparing this data to the list from 5 years ago, the major changes were the decline of the University of Hong Kong (from 21 to 43), POSTECH (from 28 to 60), and the University of Adelaide (Australia) (from 73 to below 200) and the major rise of Seoul National (from 109 to 44). One note, I find it very interesting that no Indian University was even in the top 200 in the THE overall rankings.

THE also provides a breakdown by several broad categories. The ones of greatest interest to this analysis are: Physical Sciences and Engineering/Technology. Within Physical Sciences, the highest ranked Asia/Pacific institutions are: University of Tokyo (16), University of Melbourne (24), Australian National University (29), Peking University (32), Kyoto University (36), National University of Singapore (41), Tsinghua University (70), Tokyo Institute of Technology

(83), University of Hong Kong (86), KAIST (87), and University of Queensland (95). The biggest change from five years ago was POSTECH dropping from 26 to out of the top 100. Within Engineering/Technology, the highest ranked are: National University of Singapore (13), Hong Kong University of Science and Technology (21), Tsinghua University (24), KAIST (25), University of Tokyo (27), Seoul National University (29), University of Melbourne (32), Nanyang Technological University (33), Kyoto University (39), POSTECH (41), University of Hong Kong (42), University of Queensland (43), Peking University (47), Monash University (49), University of Sydney (50), Tokyo Institute of Technology (58), National Taiwan University (63), Tohoku University (64), University of New South Wales (68), City University of Hong Kong (80), Hong Kong Polytechnic (89), and University of South Australia (99). The biggest changes from 5 years ago are the addition of KAIST from below the top 50 to 25 in the current list and the removal of Australian National University from 44 to below the top 100. Again, note the absence of any Indian institutions from this list. Given the worldwide fame of Indian Institute of Technology in producing software engineers I find that very surprising (although clearly the ability to teach software engineering does not have to be directly correlated to publishing software engineering research).

QS

The QS rankings are based on somewhat more subjective criteria than the THE rankings: 40% from academic reputation based on a very large-scale global survey (over 46,000 respondents), 10% based on a survey of potential employers on university graduates (again from a very large-scale global survey, 20% on the faculty-student ratio, 20% on literature citations per faculty, 5% based on the proportion of international students, and 5% based on the proportion of international faculty. They explicity reject financial metrics claiming both the difficulty of verification and the uncertainty based on exchange rate fluctuation.

25 Asia/Pacific institutions are in their top 100 ranks: the National University of Singapore (24), University of Hong Kong (26), Australian National University (27), University of Melbourne (31), University of Tokyo (32), the Hong Kong University of Science and Technology (34), Kyoto University (35), Seoul National University (tied for 35), University of Sydney (38), the Chinese University of Hong Kong (39), Nanyang Technical University (41), University of Queensland (43), Peking University (46), Tsinghua University (48), University of New South Wales (52), Osaka University (55), KAIST (60), Tokyo University of Technology (66), Monash University (69), Tohoku University (75), National Taiwan University (82), University of Western Australia (84), Fudan University (China) (88), University of Auckland (94), and Nagoya University (99). Five years ago there were only 15 Asia/Pacific institutions on the list, the growth coming mainly from Korea and China.

I believe the considerable disparity between the QS and the THE rankings is due to three reasons: first the greater emphasis on teaching issues in the QS rankings, second the use of extensive polling data which would tend to be a more sensitive measure of the considerable growth in reputation of academic institutions in Asia/Pacific among their peers in other parts of the world, third while I'm not sure that I believe all financial data is not to be trusted, it is true that far greater absolute external dollar equivalents are needed to fund university research in the

U.S. and Europe than in Asia/Pacific because of the fact that almost all faculty and native student salaries and stipends are funded by institutional or block government grants in those regions.

QS publishes a separate ranking of Asian universities based on a somewhat different ranking system, reflecting, they claim a modified Asian-centric view of what contributes to an institutions reputation and quality. This system uses: 30% academic reputation, 10 employer reputation, 20% faculty student ratio, 15% citations per paper, 15% number of papers per faculty, 2.5% proportion of international faculty, 2.5% proportion of international students, 2.5% proportion of inbound exchange students, and 2.5% proportion of outbound exchange students. QS probably has done the most comprehensive study of universities in Asia, actually ranking the top 300 (and remember Pacific nations are not included). This makes it a usefully comprehensive list for essentially all universities potentially worth AFOSR visits/funding in Asia. The top 50 in the current ranking are: Hong Kong University of S&T, National Univ. of Singapore, Univ. of Hong Kong, Seoul National Univ., Peking Univ., KAIST, POSTECH, Chinese Univ. of Hong Kong, Univ. of Tokyo, Kyoto Univ., Nanyang Tech. Univ., City Univ. of Hong Kong, Tokyo Inst. of Tech., Tsinghua Univ., Osaka Univ., Yonsei Univ. (Korea), Tohoku Univ., Nagoya Univ., Korea Univ., Kyushu Univ., Sungkyunkwan Univ. (Korea), National Taiwan Univ., Fudan Univ. (China), Hokkaido Univ., Hong Kong Polytechnic Univ., Univ. of S&T of China, Shanghai Jiao Tong Univ., Zhejiang Univ. (China), Nanjing Univ. (China), National Chaio Tung Univ. (Taiwan), National Tsing Hua Univ. (Taiwan), Keio Univ. (Japan), Universiti Malaya (Malaysia), Univ. of Tsukuba (Japan), Kyung Hee Univ. (Korea), Hanyang Univ. (Korea), National Cheng Kung Univ. (Taiwan), Indian Inst. of Tech. Delhi, Indian Inst of Tech. Bombay, Ewha Womans Univ. (Korea), Kobe Univ., Mahidol Univ. (Thailand), Hong Kong Baptist Univ., Waseda Univ. (Japan), National Yang Ming Univ. (Taiwan), Beijing Normal Univ., Hiroshima Univ., Chulalongkom Univ. (Thailand), Indian Inst. of Tech. Madras, and Taipei Medical Univ. (Taiwan). The entire list of 300 top universities in Asia can be found at http://www.topuniversities.com/university-rankings/asian-university-rankings/2013.

QS also has by far the most comprehensive rankings by subject area. They base their rankings using five factors: Academic reputation from the extensive survey describe above, employer reputation, average citations per paper, the "H-index," invented by Joel Hirsch, a UCSD physicist as a way of measuring theoretical physicists' relative quality in both productivity and impact (details can be found at http://en.wikipedia.org/wiki/H-index), and their own methodology for attempting to separate individual discipline strength from the overall reputation of the particular institution. Five of the areas they examine are particularly relevant to AFOSR: computer science, mathematics, physics/astronomy, chemistry, and materials sciences.

In computer science 33 Asia/Pacific universities were in the top 100: National Univ. of Singapore (8), Univ. of Hong Kong (10), Hong Kong Univ. of S&T (12), Univ. of Melbourne (13), Chinese Univ. of Hong Kong (19), Univ. of Tokyo (20), Australian Natl. Univ. (21), Nanyang Tech. Univ. (22), Univ. of Sydney (24), Univ. of Queensland (25), Tsinghua Univ. (27), Univ. of New South Wales (29), Peking Univ. (35), Univ. of Auckland (38), KAIST (40), Monash Univ. (45), Hong Kong Polytechnic (49), with the remaining in a broad 51-100 range: City Univ. of Hong Kong, Indian Inst. of Tech. Bombay, Indian Inst. of Tech. Delhi, Indian Inst. of Tech. Kanpur, Kyoto Univ., National Taiwan Univ., National Taiwan Univ. of S&T, Osaka Univ., Queensland Inst. of Tech. (Australia), Seoul Natl. Univ., Shanghai Jiao Tong Univ.,

University of Adelaide, Univ. of S&T China, Univ. of Tech. Sydney, Zhejian Univ. (China), and Tokyo Inst. of Tech. In should be noted that in this discipline, more than in any other measured by QS there has been a remarkable growth in both number (7 new universities in the region added to the top 100) and rank (with most of the universities in Australia, China, and Singapore moving up 10+ locations in rank) just in the last three years.

In mathematics 26 Asia/Pacific universities were in the top 100: Natl. Univ. of Singapore (9), Australian Natl. Univ. (16), Univ. of Tokyo (22), Chinese Univ. of Hong Kong (25), Kyoto Univ. (26), Univ. of Sydney (27), Univ. of Melbourne (30), City Univ. of Hong Kong (32), Peking Univ. (35), Tsinghua Univ. (37), Univ. of New South Wales (39), Hong Kong Univ. of S&T (40), Univ. of Hong Kong (44), Fudan Univ. (45), Nanyang Tech. Univ. (46), Univ. of Auckland (47), Univ. of Queensland (also 47), and in the 51-100 range: KAIST, Monash Univ., Natl. Cheng Kung Univ. (Taiwan), Natl. Taiwan Univ., Osaka Univ., Seoul Natl. Univ., Shanghai Jiao Tong Univ., Hong Kong Polytechnic Univ., and Univ. of Science and Tech. China.

In physics/astronomy 20 Asia/Pacific universities were in the top 100: Univ. of Tokyo (9), Kyoto Univ. (19), Tohoku Univ. (25), Tokyo Inst. of Tech. (27), Peking Univ. (29), Osaka Univ. (30), National Univ. of Singapore (32), Nagoya Univ. (37), Seoul National Univ. (38), Tsinghua Univ. (43), Australian Natl. Uni. (49), and in the broad 51-100 range: Fudan Univ. (China), KAIST, Nanyang Tech. Univ., Natl. Taiwan Univ., POSTECH, Hong Kong Univ. of S&T, Univ. of Sydney, Univ. of Hong Kong, and Univ. of S&T China.

In chemistry, 28 Asia/Pacific universities were in the top 100: Univ. of Tokyo (6), Kyoto Univ. (11), Natl. Univ. of Singapore (13), Peking Univ. (15), Tokyo Inst. of Tech (17), Tsinghua Univ. (18), Osaka Univ. (20), Univ. of Hong Kong (also 20), Univ. of Melbourne (23), Hong Kong Univ. of S&T (24), Seoul Natl. Univ. (29), Univ. of Sydney (30), KAIST (31), Monash Univ. (33), Tohoku Univ. (35), Nagoya Univ. (36), National Taiwan Univ. (46) Nanyang Tech. Univ. (49), and in the 51-100 range: Australian National Univ., Fudan Univ., Indian Institute of Science, Korea Univ., Kyushu Univ. Nanjing Univ., POSTECH, Shanghai Jiao Tong Univ., Univ. of Queensland, Univ. of S&T China.

In materials sciences, a remarkable 35 Asia/Pacific universities were in the top 100 (with 19 in the top 50): Natl. Univ. of Singapore (6), Tsinghua Univ. (10), Nanyang Tech. Univ. (14), Univ. of Tokyo (16), Tohoku Univ. (17), Peking Univ. (20), Seoul Natl. Univ. (23), Hong Kong Univ. of S&T (also 23), Kyoto Univ. (25), Univ. of New South Wales (also 25), Tokyo Inst. of Tech. (28), Shanghai Jiao Tong Univ. (29), Natl. Taiwan Univ. (34), KAIST (35), Osaka Univ. (36), Monash Univ. (42), Univ. of Queensland (43), POSTECH (49), Indian Inst. of Science (50), and in the 51-100 range: Australian Natl. Univ., Fudan Univ., Indian Inst. of Tech. Bombay, Indian Inst. of Tech. Kanpur, Indian Inst. of Tech. Kharagpur, Kyushu Univ., Nagoya, Univ., Natl. Cheng Kung Univ., Natl. Tsing Hua Univ., Sungkyunkwan Univ. (Korea), Chinese Univ. of Hong Kong, Univ. of Hong Kong, Univ of S&T China, Univ. of Wollongong (Australia), Yonsei Univ., and Zhejiang Univ.

ARWU

The third ranking system, the Academic Ranking of World Universities (ARWU), comes from the Center for World-Class Universities at Shanghai Jiao Tong University. Unlike the prior two that come from commercial enterprises and whose "customers" are the individual institutions and potential attendees at those institutions, ARWU was motivated since its foundation in 2003 by the desire of the Chinese government to determine and improve the standing of Chinese universities. Its customer base is now considered to be governments and educational foundations concerned with overall health of their nations' university system. The focus is entirely on academic prowess among research universities, and as such it may be the most relevant comprehensive ranking system for AFOSR purposes (with the major caveat noted below). The rankings are solely based on six objective (and easily verified) measures: 10% on the number of alumni winning Nobel Prizes and Fields Medals, 20% on staff of the institution winning Nobel Prizes and Fields Medals, 20% on the number of "highly-cited" researchers in 21 broad subject categories (This comes from the Thomson Reuters continuing study of all papers covered in the Web of Science and represents less .5% of all publishing scholars. The list and detailed methodology can be found at http://www.highlycited.com/ , and is itself, I believe, a useful resource for AFOSR), 20% on papers published in Nature and Science, 20% on papers indexed in the Science Citation Index and Social Science Citation Index, and 10% on per capita performance (the sum of the weighted scores of the five other measures divided by the full-time equivalent number of academic staff at the university).

In the most recent rankings, only eight institutions in the Asia/Pacific region made the top 100: The University of Tokyo (21), Kyoto University (26), University of Melbourne (54), Australian National University (66), Osaka University (85), University of Queensland (also 85), University of Western Australia (91) and University of Sydney (97). 9 others are in the 101-150 range: Hokkaido University, Monash University, Nagoya University, National University of Singapore, National Taiwan University, Seoul National University, Tohoku University, Tokyo Institute of Technology, and University of New South Wales. 7 are in the 121-200 range: Fudan University, Kyushu University, Peking University, Tsinghua University, Shinghai Jiao Tong University, University of Tsukuba, and Zhejiang University.

Why the considerable disparity in the height of the rankings of the best Asia/Pacific universities compared to the prior two ranking systems? There are a few likely reasons. First of all, the metrics used here take time to develop, particularly in the Nobel Prize/Field Medal categories. With many of the Asia/Pacific universities only recently rising in worldwide prominence, they are only now creating the future Nobel Laureates among their students and faculty. Second, the strong reliance on citations and especially on "high-cited" researchers is also a metric that rewards years of skilled scientific research. In contrast, the more subjective reputation survey and similar measures of the other systems reward recent accomplishments more quickly, so those universities with young, highly capable researchers just entering the height of productivity of their careers will achieve prominence on the THE and QS lists several years before the ARWU list. The corollary to that is that universities on the decline will remain on the ARWU list for longer (although they do make an attempt to reduce that condition by weighting the recency of major prizes).

ARWU also provides rankings (using similar measures) of both broad areas (like science and engineering/technology) and specific subjects. In the Science rankings, 3 Asia/Pacific universities make the top 50: Univ. of Tokyo (9), Kyoto Univ. (17), and Tohoku Univ. (49). In the 51-75 range are: Tohoku Univ., Osaka Univ., Nagoya Univ., and Tokyo Inst. of Tech. In the 76-100 range are: National Taiwan Univ. and Peking Univ., And in the second 100 are Nanjing Univ., National Tsing Hua Univ., Seoul National Univ., Chinese Univ. of Hong Kong, University of Western Australia, Tsinghua Univ., Univ. of Melbourne, S&T Univ. China, Univ. of Tsukuba, Hokaido Univ. Indian Inst. of sci., Kyushu Univ. Macqurie Univ. (Australia), Monash Univ., National Univ. of Singapore, Shanghai Jiao Tong Univ., Univ. of Queensland, Waseda Univ. (Japan), and Zhejiang Univ.

In the Engineering/Technology rankings (which include computer science), the ranking methodology is significantly different. Alumni and Faculty awards are not used, 25% is given to highly cited researchers in engineering, computer science, and materials science, 25% to papers to the Science citation index for all engineering fields, 25% to the percentage of papers published in the top fifth of engineering journals compared to all engineering journals, and 25% engineering related funding at the university. I would guess this produces a much more dynamic ranking and the results seem to bear that out. 11 Asia/Pacific universities make the top 50: Tohoku Univ. (24), City Univ. of Hong Kong (25), National Taiwan Univ. (26), Hong Kong Univ. of S&T (34), Tsinghua Univ. (35), Kyoto Univ. (36), Tokyo Inst. of Tech. (42), KAIST (44), Nanyang Tech. Univ. (47) Zhejiang Univ. (48), and Univ. of S&T China (49). In the 51-75 range are Monash Univ., National Cheng Kung Univ., National Chio Tung Univ., National Tsing Hua Univ., National Univ. of Singapore, Osaka Univ., Shangjai Jiao Tong Univ., Chinese Univ. of Hong Kong, Univ. of Melbourne, Univ. of New South Wales, and Univ. of Sydney. In the 76-100 range are: Harbin Inst. of Science (China), Indian Institute of Science, National Taiwan Univ. of S&T, Seoul National Univ., Hong Kong Polytechnic Univ., and the University of Queensland. There are 32 more in the next 100. The total list can be found at http://www.shanghairanking.com/FieldENG2013.html.

The rankings in the individual fields of mathematics, physics, chemistry, and computer science use a methodology similar to the total rankings with Fields Medals used for mathematics, Nobel Prizes for chemistry and physics, and Turing Awards used for computer science. The per capita measure is replaced by the measure of percentage of total publications in the top 20% of journals for that field. So I would expect this goes back a more time-weighted list than in engineering.

For mathematics only two Asia/Pacific universities made the top 50: Kyoto Univ. (18) and Chinese Univ. of Hong Kong (50). Univ. of Tokyo is in the 51-75 range. In the 76-100 range are Harbin Inst. of Tech., Peking Univ., Tokyo Inst. of Tech., Univ. of New South Wales, and Waseda Univ. 28 more make the next 100. The total list can be found at http://www.shanghairanking.com/SubjectMathematics2013.html.

For computer science 8 Asia/Pacific universities made the top 50: Hong Kong Univ. of S&T (24), Chinese Univ. of Hong Kong (29), National Taiwan Univ. (33), Nanyang Tech. Univ. (35), National Chia Tung Univ. (also 35), Tsinghua Univ. (37), City Univ. of Hong Kong (42), and KAIST (44). In the 51-75 range are Indian Inst. of Science, National Univ. of Singapore, Hong Kong Polytechnic Univ., Univ. of Hong Kong, and Zhejiang Univ. In the 76-100 range are

National Cheng Kung Univ., National Taiwan Univ. of S&T, Peking Univ., and Shanghai Jiao Tong Univ. 26 more make the next 100. The complete list can be found at http://www.shanghairanking.com/SubjectCS2013.html. I must admit to be rather shocked by one part of this evaluation, the absence of any Australian universities from the top 50, not to mention the top 100. This runs contrary to my own extensive experience as a collaborator and funder of computer science work in Australia and directly counter to the QS rankings for computer science. I am not quite sure what in the metrics runs counter to ranking the Australian institutions higher.

For physics 4 Asia/Pacific universities make the top 50: Univ. of Tokyo (7), Australian National Univ. (28), Kyoto Univ. (34), and Tohoku Univ. (48). Osaka Univ. and Tokyo Inst. of Tech. are in the 51-75 range. Nagoya Univ., Swinburne Univ. of Tech. (Australia) and Seoul National Univ. make the 76-100 range. Nanjing Univ., National Taiwan Univ., Peking Univ., Univ. of Western Australia, Tokyo Metropolitan Univ., Tsinghua Univ., Univ. of Melbourne, Univ. of S&T China, Univ. of Sydney, Tsukuba Univ., Waseda Univ., Korea Univ., Nanyang Tech. Univ., National Univ. of Singapore, and Sungkyunkwan Univ. and in the next 100.

For chemistry, 7 Asia/Pacific universities make the top 50: Kyoto Univ. (9), Univ. of Tokyo (11), Tohoku Univ. (28), Nagoya Univ. (34), Tokyo Inst. of Tech. (38), National Tsing Hua Univ., and Indian Inst. of Science. In the 51-75 range are Kyushu Univ., Monash Univ., Nanjing Univ., Nanyang Tech. Univ., Oaska Univ., Fudan Univ., Hokaido Univ., Jilin Univ. (China), National Univ. of Singapore, Peking Univ., Chinese Univ. of Hong Kong, Univ. of Hong Kong, Univ. of Western Australia, Tsinghua Univ., Univ. of New South Wales, Univ. of S&T China, Univ. of Sydney, and Zhejiang Univ. 27 more are in the next 100. The complete list can be found at http://www.shanghairanking.com/SubjectChemistry2013.html.

University of Groningen

As discussed above, I examined three other more specialized ranking lists. The University of Groningen in the Netherlands publishes their list of "The top 100 large comprehensive research universities in the world." These are ranked solely by the ratio of citations to papers published with a minimum of 20,000 published papers in recognized academic journals over the period 1998-2008. This provides a pretty good metric of historical quality of publications from those universities, although given it hasn't been updated for five years it is only of limited value for our purposes. According to their list n Asia/Pacific universities were in the top 100: Univeristy of Tokyo (70), Osaka Univ. (71), Kyoto Univ. (74), Univ. of Melbourne (80), Univ. of Sydney (86), Nagoya Univ. (87), Univ. of Queensland (88), Tohoku Univ. (96), Kyushu Univ. (97), Hokkaido Univ. (98), National Univ. of Singapore (99), and Seoul National Univ. (100). The entire list is available at http://www.rug.nl/bibliotheek/search/elektijdschr/rankinglist for those who wish to see actual numbers of publications and citations (Harvard topped both at 94,117 papers and 2,543,539 citations and the highest ratio of 27.03.

Nature Global Publishing Index

The Nature Global Publishing Index takes the simple approach of counting the number of articles from an institution that appear in any given year in journal Nature and 17 other affiliated journals in the Nature publishing family. This is scaled to take account of multiple authorship in giving "credit" to any one institution. This is a very useful measure for fields of science where Nature and its family of journals are a main archival place of choice; this is especially true in the biological sciences, not as dominant in chemistry, physics, and materials sciences, and hardly relevant in mathematics, computer science, and cognitive sciences. The U.S. is far and away the global leader by this metric with 2236 articles in 2012 (and a weighted score of 1638.92) which is more than the next ten nations. As far as the Asia/Pacific region goes, 9 countries are in the Top 50: Japan (4), China (6), Australia (10), Korea (13), Singapore (19), Taiwan (21), India (24), New Zealand (28), and Vietnam (45). In the Top 100 individual institutions for the Asia/Pacific region are: Univ. of Tokyo (9), Kyoto Univ. (26), the RIKEN Institute (Japan) (33), Osaka Univ. (36), Univ. of Melbourne (62), Nagoya Univ. (65), Univ. of S&T China (72), National Univ. of Singapore (75), Tohoku Univ. (84), Tsinghua Univ. (88), Peking Univ. (93), and Australian National Univ. (94).

Apart from the rankings, the document describing the index does an extensive analysis of trends over the period of 2008-2012 and provides extensive charts comparing countries, regions, and different fields of science. It also provides a detailed look at a dozen countries where there are major upward (China) or downward (Japan) trends over that period. For that reason alone the document is well worth reading. It can be found at http://www.natureasia.com/en/publishing-index/pdf/NPI2012_Global.pdf.

Webometrics

Finally, reflecting the importance of the Web in scientific communications, the Cybermetrics Lab of the Spanish National Research Council began in 2004 an extensive analysis of web presence and impact, called Webometrics, in order to measure the performance of universities. (I hope we all remember that the Web itself started as a way for the experimental physics community to easily share preprints of research papers). They were heavily influenced by the methodology used in the ARWU rankings. Included in the metrics are "impact" as measured by number and variety of links to web-presented information from an institution, and "activity" as measured by total number of webpages, number of openly available scientific documents on the web, and number published in high impact international journals. As might be expected U.S. universities dominate the top 100 in the rankings with 43 of the top 50. The highest ranked Asia/Pacific university is the National Univ. of Singapore (54), followed by Tsinghua Univ. (57), Univ. of Tokyo (63), National Taiwan Univ. (66), Peking Univ. (67), Australian National Univ. (74), Zheijiang Univ. (76), Wuhan Univ. (92), Shanghai Jiao Tong Univ. (94) and Univ. of Melbourne (100).

The webometrics site http://www.webometrics.info/en, provides an extensive set of regional and countrywide rankings along with tools for further analysis. Their goal is to promote international research collaboration by increasing open communications among scientists using the Web. In

terms of utility for AFOSR the rankings are probably most useful in areas like computer science and social technologies, but they do provide a very current analysis of fast-growing universities throughout the globe.

Analysis and Recommendations

So what can we learn for both AFOSR International Asia/Pacific as an organization and for individual Program Officers attempting to discover appropriate basic research to fund from all of the data discussed in this section? Here are some thoughts:

1. We certainly have a plethora of evidence that the best modern science and technology research is truly global. While U.S. universities continue to dominate the top few spots in all the rankings, rapidly increasing numbers of institutions in Asia/Pacific are joining the upper ranks.
2. This is particularly true in the newest fields of science surveyed, particularly computer science and materials sciences where traditional U.S. top-ranked universities (e.g Cornell in computer science) are ranked in some surveys below a dozen or more Asia/Pacific universities.
3. A deeper analysis of trending information is probably worthwhile. I have noted some examples, but one could spend months studying by countries and fields (as the Nature Global Publishing staff did for a few countries) in order to determine which universities are attracting the most "stars." After all, the goal of any science funder is to discover and fund the next Nobel Laureate, Fields Medal, or Turing Award winner—anyone can fund the previous ones!
4. While there are surely individual talented researchers throughout the region, Japan (even if for several reasons it is in a downward trend), Korea, Singapore, Taiwan, and Australia have almost all of the key institutions we should be examining as institutions. In India, with the second largest (and in the not so distant future largest) population in the world only the Indian Institute of Science and several of the Indian Institutes of Technology made even the top 200 in any category or ranking. In New Zealand, only the University of Auckland was prominent.
5. So since, we don't have as a stated goal nurturing new scientific centers in the region, but rather discovering the best and brightest already there, we probably should limit our "scouting trips" to those five countries while continuing to fund individual gems we find through other means (conferences, word of mouth, web research, etc.)
6. From examining the data, it would seem that several universities in Singapore are truly world-class. While we do fund some research in Singapore, it is probably worth a field trip or two to the National University of Singapore and Nanyang Technological University given how highly ranked they are both across the board and in many disciplines.
7. The 800-pound (and getting larger by leaps and bounds) gorilla of Asian science and technology is clearly China including the special case of Hong Kong. More of those universities are now in the top tier than even the best Japanese and Australian universities. We need to clarify the policies on funding research in Hong Kong and also invest in a very detailed analysis through field trips of all of the key Chinese universities.

8. Despite what I said above India really should be thought of as a special case. We should develop a strategy that avoids funding mediocre work, but still make sure we are abreast of the rapid growth of science and technology that surely must come within the next decade or so as it has done so in China the past decade.
9. For new Program Officers, this data should serve as an excellent starting point especially if those POs are not already long-standing members of the academic research community. For example, in the QS rankings there are a remarkable 35 Asia/Pacific universities that rank among the top 100 in the world in materials sciences. It would seem to make sense to make it a goal for a materials sciences PO to visit most if not all of those during the first year of his or her tenure.

II. Country-Specific Analysis

III. Discipline-Specific Analysis

IV. Overall Recommendations for Investment and Further Discovery